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Field study on the influence of spatial and environmental characteristics on the evaluation of subjective loudness and acoustic comfort in underground shopping streets

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Abstract

A large-scale measurement and subjective survey was undertaken in five underground shopping streets to determine the influence of spatial and environmental characteristics on users' subjective loudness and acoustic comfort. The analysis on the spatial characteristics shows that the subjective loudness is higher in "street type" than in "square type" underground shopping streets when the equivalent continuous A-weighted sound pressure level (LAeq) is relatively high (75 dBA). Acoustic comfort is higher in "square type" than in "street type" underground shopping streets where LAeq is relatively low (55 dBA). Considering spatial functions, it is found that acoustic comfort is higher in a dining area than in a shopping area. In terms of environmental characteristics where air temperature, relative humidity, luminance and visual aspect were considered, the subjective loudness is influenced by humidity and luminance, with correlation coefficients of 0.10 to 0.30. The evaluation of acoustic comfort is influenced by air temperature, humidity, and luminance, with correlation coefficients of 0.1 to 0.4. There are significant correlations between the evaluation of environmental factors and subjective loudness, as well as, acoustic comfort. The correlation coefficients are 0.1 to 0.5. Moreover, respondents' attitude to sound environment could influence their evaluation of subjective loudness and acoustic comfort.

Keywords (Spatial type; environmental characteristics; underground shopping street; acoustic comfort; subjective loudness; sound level)

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1. Introduction

With the exploitation and utilisation of underground spaces, underground shopping streets have become one of the primary commercial spaces in urban areas in many cities worldwide. For example, over 0.40 km^2 of underground shopping streets in Harbin, China were constructed between 2004 and 2008 [1]. Among various problems arising from underground shopping streets, subjective loudness and acoustic comfort have been an important issue for architects, owners, administrators, and customers [2]. Some studies have been carried out in terms of noise reduction and sound insulation in underground shopping streets [3-4], but research is still limited in terms of subjective loudness and acoustic comfort.

Previous studies suggested that the sound environment evaluation of a space depends strongly on the specific characteristics of the space, as well as various physical environmental conditions [5-8]. For example, reverberation was intensely researched in the analysis of spatial characteristics, and street music is considered suitable at a reverberation time (RT) range of 1s to 2s [9-10]. At a constant sound pressure level (SPL), noise annoyance was observed to be greater with longer reverberation [11]. In terms of audiovisual interaction, Southworth [12] found that attention to visual form reduces the conscious perception of sound when aural and visual settings were coupled, and vice versa. The interaction between auditory and visual perception gives people a sense of involvement, leading to more comfort especially when the auditory and visual components are coherent. Previous studies [13-17] indicated that the auditory judgement can be influenced by visual settings. Unlike visual factor, effects of other physical factors, like temperature and relative humidity in the environment, are less considered, although the importance has been demonstrated [18-19], even for species diversity [20].

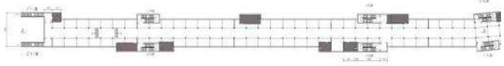
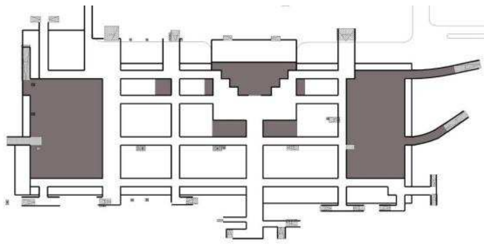
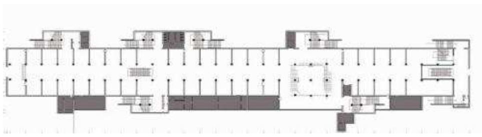
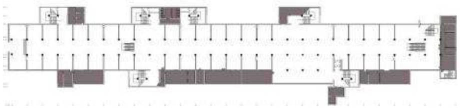
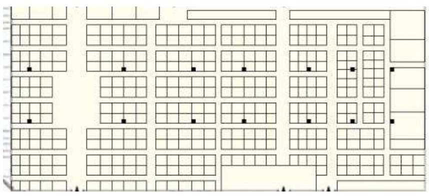
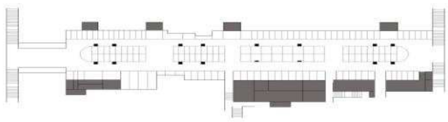
This study, therefore, based on a series of subjective surveys and sound environment measurements in underground shopping streets, examines the influence of a number of spatial and environmental factors on subjective loudness and acoustic comfort. The spatial factors include space types, floor level, and functions; and the environmental factors include air temperature, relative humidity, luminance and visual aspect.

2. Methodology

Underground shopping streets in Harbin, China have a special historical background and include various general space types. This research selected five typical underground shopping streets in Harbin as survey sites. These streets are categorised into two types: the “street type,” which is viewed as a long space, such as the Shi Tou Dao, Qiu Lin, and Le Song underground shopping streets, and; the “square type,” which is viewed as a flat space, such as the Railway Station and Hui Zhan underground shopping streets; as shown in Table 1. Subsequent questionnaire surveys on the sound environment were conducted over four seasons, from winter of 2007 to autumn of 2008, in the five selected underground shopping streets in Harbin. Over 2800 interviews were conducted in the five sites, approximately 400 to 600 interviews in each site, using identical questionnaires. The questionnaire was introduced as an enquiry on general environmental conditions, for example, including the evaluation of thermal conditions and the visual environment, instead of concentrating solely on acoustic environment, to avoid any possibility of bias towards the acoustic aspect [21-22].

SPL measurement was conducted immediately after each interview. In the measurement, the microphone of the sound level meter was positioned approximately 1 m away from any reflective surfaces and 1.2 m to 1.5 m away above the floor to reduce the effect of acoustic reflection [23]. This method of measurement was also used in indoor SPL measurement of previous studies [23-26]. The sound level meter was set in slow-mode, and reading was taken every 3 s to 5 s. A total of 100 measurement data were obtained in each survey position, and corresponding LAeq was derived. The interviews as well as measurements were carried at a number of representative locations, typically 5-7, at every survey site, given that in such spaces there is generally no significant difference between different locations, although an alternative method would be to use gird points and draw a contour map.

Table 1. Basic information of the survey sites, including size, floor plan, and the number of interviews conducted.

Sites	Size (m^2)	Floor plan	Number of interviews
Shi Tou Dao (street type)	17000		598
Railway Station (square type)	50000		446
Qiu Lin (street type)	14000	 The first floor underground  The second floor underground	459
Hui Zhan (square type)	30000		690
Le Song (street type)	15000		629

Simultaneously, the air temperature and relative humidity were measured using a temperature and humidity meter HMI41, with the probe positioned at 1.5 m above the floor and approximately 1 m away from any wall [27-28]. The luminance was measured using a luminance meter TES1336A, at 1.64 m above the floor, namely the average eye altitude of a Chinese man [29-30].

The subjective loudness, acoustic comfort, perceived humidity, brightness evaluation and visual evaluation were also included in the questionnaire survey [31], and in Table 2, only some surveyed and measured factors are listed. It is noted that the perceived humidity was used in this research instead of humiture, given that perceived humidity is more subjective, while humiture is more objective [32-33]. Before the interview, interviewers usually explained the interviewees the questions [34]. For acoustic comfort evaluation, for example, users were told that it means their general evaluation of acoustic comfort when they heard all the sounds in the survey sites. The actual question was: 'Please evaluate the general acoustic comfort at the moment at this location by ticking one of the following boxes', where a five point linear scale was used, with 1, very uncomfortable; 2, uncomfortable; 3, neither comfortable nor uncomfortable; 4, comfortable; and 5, very comfortable. It is noted in the table that for SPL, relative humidity and luminance, the actual numerical values are used, whereas for temperature, the data are divided into 5 categories.

Table 2. Factors considered in the measurements and subjective evaluation.

Factors	Measures of the attributes
SPL	dBA
Air temperature	°C, scale 1 to 5, with 1 as <10℃, 2 as 10-15℃, 3 as 15- 20℃, 4 as 20-25℃ and 5 as >25℃
Relative humidity	%
Horizontal luminance	lux
Subjective loudness	Scales 1 to 5, with 1 as very low and 5 as very high
Acoustic comfort	Scales 1 to 5, with 1 as very uncomfortable and 5 as very comfortable
Heat evaluation	Scales 1 to 5, with 1 as very uncomfortable and 5 as very comfortable
Perceived humidity	Scales 1 to 5, with 1 as very uncomfortable and 5 as very comfortable
Brightness evaluation	Scales 1 to 5, with 1 as very uncomfortable and 5 as very comfortable
Visual evaluation	Scales 1 to 5, with 1 as very uncomfortable and 5 as very comfortable

The results were analysed using SPSS Software 15.0 [35], considering the linear and nonlinear correlations using Pearson/Spearman correlations (two-tailed), as well as mean differences (t-test, two-tailed) for factors with two scales, and Pearson chi-square for factors with more than three scales.

3. Influence of spatial characteristics

Based on the survey and the measurement results, this section presents the effect of spatial characteristics on the evaluation of the acoustic environment.

3.1 Space type

LAeq varied in different survey sites, therefore, three distinctive LAeq were chosen in this study, namely 55, 65, and 75 dBA corresponds to low, medium, and high sound levels, respectively. Each level has a range of 4 dBA: low LAeq with 53 dBA to 57 dBA (231 data); medium LAeq with 63 dBA to 67 dBA (465 data); and high LAeq with 73 dBA to 77 dBA (871 data). The values outside these ranges were relatively few, so that in this analysis, these values were not considered. The mean subjective loudness and acoustic comfort are given in Figure 1, based on the three LAeq categories in different underground shopping streets.

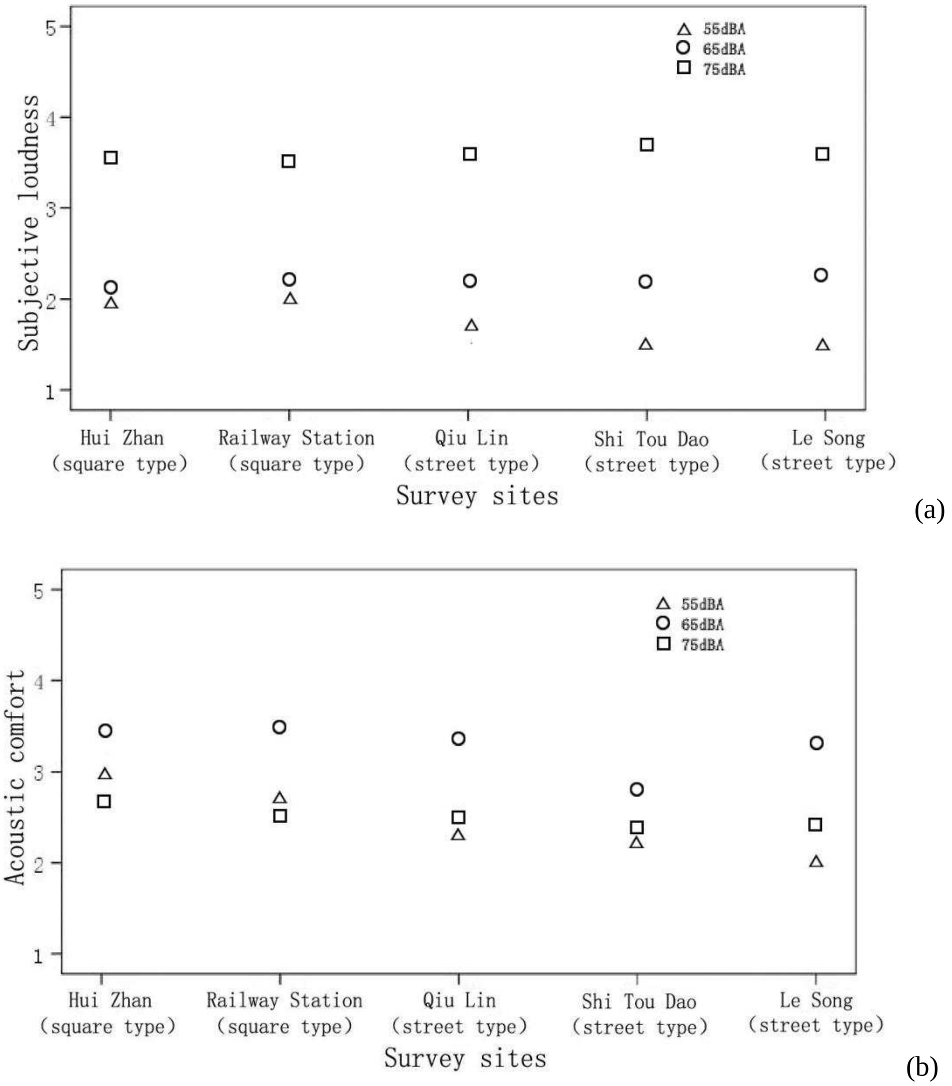


Figure 1. Relationship between the sound level and subjective loudness (a), as well as acoustic comfort (b) in different types of underground shopping street

Figure 1a shows that there is an increase in subjective loudness, only by 0.20 to 0.70, as LAeq was changed from 55 dBA to 65 dBA in the survey sites. This result again shows that, to some degree, say 55-65dBA in underground shopping streets, LAeq is not a good indicator of subjective loudness.

The subjective loudness is significantly increased by an average of 1.20 to 1.60 when LAeq was increased from 65 dBA to 75 dBA. The subjective loudness in “square type” underground shopping streets is notably higher than that in “street type”. The mean difference ranges from 0.30 to 0.50 with LAeq= 55 dBA. However, there is insignificant difference between the two types of underground shopping streets with LAeq=65 dBA. The subjective loudness in “street type” underground shopping streets is slightly higher than that in “square type” with LAeq=75 dBA, with a mean difference ranging from 0.10 to 0.30. In other words, the subjective loudness of the “square type” underground shopping street is higher than that in the “street type” if LAeq is relatively low, whereas the subjective loudness of the “street type” is higher when LAeq is relatively high. A possible reason, based on site observation, is that, the LAeq was lower when there were fewer users, and the echoes were more evident in the "square type" underground shopping street, resulting in higher subjective loudness. On the other hand, the LAeq was high when there were more people, and the crowded appearance in the "street type" influenced people's perception psychologically, creating a higher level of subjective loudness.

Figure 1b shows a higher acoustic comfort level with LAeq=65 dBA than that with LAeq=55 dBA and 75 dBA. In a previous study [36], it was also found that the relationship between the measured LAeq and the acoustic comfort evaluation is of a parabolic shape in such spaces, where when the LAeq is lower or higher than a certain value, approximately 65dBA to 70 dBA, the acoustic comfort evaluation score becomes lower with a lower or higher LAeq. It is also interesting to note that the acoustic comfort is higher in the "square type" than that in the "street type" underground shopping streets with LAeq=55 dBA, with a mean difference between 0.40 and 1.00. Similar trends can also be observed with LAeq= 65 dBA and 75 dBA, with a mean difference of <0.70, and 0.10-0.50, respectively. In other words, the difference between the two types of underground shopping streets is greater when the LAeq is lower.

3.2 Floor level

A number of previous studies indicated that users' evaluation varies at different floor levels of the same building [37-40]. In this study, in order to test if the evaluation of acoustics is influenced by different floor levels, the mean difference in acoustic comfort is determined between the first and second floors of the Qiu Lin underground shopping street. While LAeq is a good baseline in comparing the mean difference in acoustic comfort, since in this study it is hard to find the same values of measured LAeq at different floor levels for the comparison of the evaluation of acoustic comfort, subjective loudness is used as a baseline instead. This is acceptable due to the linear relationship between LAeq and subjective loudness in underground shopping streets [36]. The mean difference in subjective acoustic comfort between the first and second floors, based on T-test of independent samples, is shown in Table 3. The table suggests an insignificant mean difference in subjective acoustic comfort between the users in the first and second floors. The similarity of both floors in the internal decoration style, the type of goods sold, the number of people, the temperature and humidity, and the primary sound source could have led to the insignificant mean difference. In other words, this result suggests that the floor level in underground shopping streets may have no significant influence on users' evaluation of acoustics, and this in turn, would be useful to understand the difference in acoustic evaluation between underground and above ground levels.

Table 3. Mean difference in acoustic comfort between the first and second floors in the Qiu Lin underground shopping street, where the significance levels (two-tailed) are also shown.

Subjective loudness	Mean difference /significance	Degree of freedom
1-very low	0.02/0.80	55
2-low	0.06/0.65	92
3-neither low or high	0.28/0.07	141
4-high	0.04/0.77	98
5-very high	0.17/0.34	65

3.3 Function

In underground shopping streets, the function of every space is different. This study focused on two space types, namely shopping and dining spaces in underground shopping streets, examining the influence of spatial function on acoustic comfort with a given subjective loudness. Shi Tou Dao and Railway Station were taken as case study sites for this.

The shopping and dining spaces in Shi Tou Dao are farther from one another, as shown in Figure 2. The mean difference in acoustic comfort between these two spaces is shown in Table 4. It can be observed that acoustic comfort was lower in the shopping space than that in the dining space whether the subjective loudness is “low”, “neither low nor high”, and “high”. The mean difference in acoustic comfort between dining and shopping spaces ranges 0.30 to 0.40. A possible reason for the difference is that most respondents in the dining space had rested, and their acoustic comfort might have increased after taking a rest.

Table 4. Mean difference in acoustic comfort between the shopping and dining spaces in the Shi Tou Dao underground shopping street, where the significance levels (two-tailed) are also shown.

Subjective loudness	Mean difference/significance	Degree of freedom
1-very low	—	5
2-low	-0.36/0.05 *	67
3-neither low nor high	-0.38/0.02 *	225
4-high	-0.30/0.01 **	81
5-very high	-0.22/0.09	66

** indicates $p<0.01$, and * indicates $p<0.05$


(a)

(b)

Figure 2. Shopping (a) and dining spaces (b) in the Shi Tou Dao underground shopping street

To verify this assumption, a small-scale survey was conducted in the Shi Tou Dao underground shopping street. The respondents were categorised as either A, those who were preparing to sit and have a rest, or B, those who have rested for a while. The survey was conducted simultaneously in 12 locations within the underground shopping street to ensure the comprehensiveness of the survey and the similarity of the environment. In each location, four respondents were selected, with two per category. In other words, a total of 48 samples were obtained, with 24 samples per category. The time of the survey was limited to 2 minutes only. The results are shown in Figure 3. It can be seen that 30% of the respondents who were resting selected “neither uncomfortable nor comfortable”, 40% chose “comfortable” or “very comfortable”, and 30% selected “uncomfortable” or “very uncomfortable”. In comparison, 45% of the people who were preparing to rest selected “neither uncomfortable nor comfortable”, 40% of the respondents chose “uncomfortable” or “very uncomfortable” and only 15% selected “comfortable” or “very comfortable”. Notably, the people who chose “very comfortable” were all individuals who have rested. In contrast, none of the people who were preparing to rest chose the "very comfortable" option. In other words, the results confirm that in terms of acoustic comfort, people who have rested are higher than those who were preparing to sit and not having a rest.

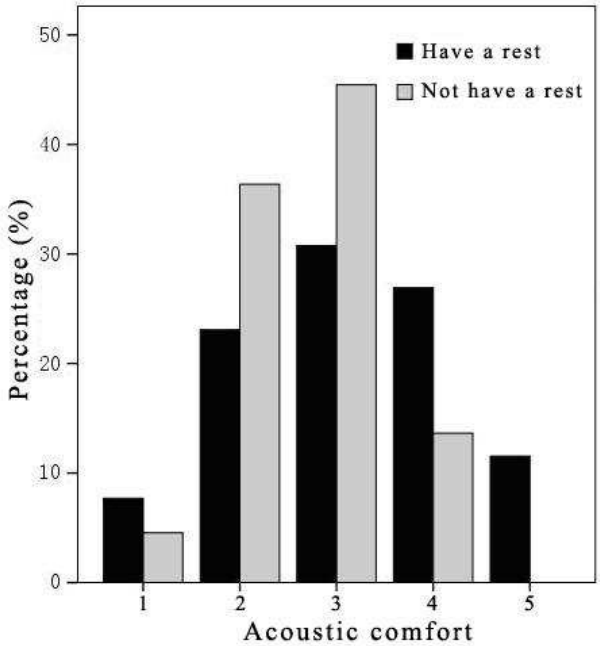


Figure 3. Comparison of acoustic comfort between users who have rested and those who have not

In the shopping space, a number of goods were sound sources themselves. Therefore, different selling spaces might affect users' acoustic comfort. The mean difference in acoustic comfort between spaces selling toys and clothes (as shown in Fig. 4) at the same subjective loudness level is shown in Table 5, where the Railway Station underground shopping street is taken as an example. It can be seen that acoustic comfort is higher in the space selling toys than that in the space selling clothes, with a mean difference ranging from 0.20 to 0.80. The mean difference in acoustic comfort notably decreased, from 0.77 to 0.21, with increased subjective loudness. When subjective loudness is 'very high', the mean difference in acoustic comfort is insignificant between these two kinds of space.

Table 5. Mean difference in acoustic comfort between toy and clothes selling areas in the Railway Station underground shopping street, where the significance levels (two-tailed) are also shown.

Subjective loudness	Mean difference/significance	Degree of freedom
1-very low	—	14
2-low	0.77/0.00 **	98
3-neither low nor high	0.56/0.00 **	112
4-high	0.21/0.05 *	105
5-very high	-0.11/0.56	83

** indicates $p<0.01$, and * indicates $p<0.05$


(a)


(b)

Figure 4. Clothes (a) and toy (b) selling spaces in the Railway Station underground shopping street

4. Influence of environmental characteristics

The influence of environmental factors in the evaluation of acoustic environment in underground shopping streets is discussed in this section in terms of subjective loudness and acoustic comfort. The ranges of the measured temperature, relative humidity and light level in these survey sites are shown in Table 6. As an important consideration in psychophysics, the just noticeable difference (JND) should be taken into account. Although the determination of accurate JND is generally related to the cutaneous feeling of air temperature or relative humidity [41], some approximate values were suggested in terms of 50% JND [42], which is no more than 5 degrees in air temperature and no more than 10% in relative humidity, in general underground environments, such as underground shopping streets or subways. From Table 6 it can be seen that this 50% JND is considerably smaller than the range of temperature or relative humidity in the survey sites. In other words, the users should certainly feel the changes in air temperature and relative humidity in the survey sites.

Table 6. The ranges of the measured temperature, relative humidity and luminance level in the survey sites.

Survey sites	Air temperature (℃)		Relative humidity (%)		Luminance level (lux)	
	Range	Mean	Range	Mean	Range	Mean
Shi Tou Dao	5-26	17.26	25-72	65.21	85-225	116.30
Railway Station	3-25	18.52	40-85	68.72	60-207	96.25
Qiu Lin	1-30	18.23	21-76	59.15	72-238	102.33
Hui Zhan	12-24	18.49	25-75	61.42	102-265	130.13
Le Song	9-26	18.61	32-82	68.54	90-280	119.26

4.1 Temperature

The relationships between air temperature and subjective loudness and between air temperature and acoustic comfort are shown in Table 7, where Chi-square test and correlation coefficient R are also given. A significant correlation coefficient of -0.11 ($p<0.01$) between air temperature and subjective loudness is only observed in Qiu Lin. Although the correlation between air temperature and acoustic comfort is significant ($p<0.01$ or $p<0.05$) in three other underground shopping streets, the correlation coefficient R is very low. These results seem to suggest that neither subjective loudness nor acoustic comfort was influenced significantly by air temperature in the survey sites.

Table 7. Chi-square test of correlation coefficients between air temperature and subjective loudness as well as acoustic comfort, where the significance levels (2-tailed) are also shown.

Survey sites	Subjective loudness (Correlation/significance)	Acoustic comfort (Correlation/significance)	Degree of freedom
Shi Tou Dao	-0.02/0.59	0.13/0.00 **	584
Railway Station	0.01/0.73	0.04/0.23	435
Qiu Lin	-0.11/0.01 **	0.05/0.22	428
Hui Zhan	-0.01/0.73	0.09/0.03 *	651
Le Song	-0.06/0.06	0.07/0.04 *	599

** indicates $p<0.01$, and * indicates $p<0.05$

The relationship between heat evaluation and subjective loudness, as well as the relationship between heat evaluation and acoustic comfort, are presented in Table 8. The correlation R between heat evaluation and subjective loudness ranges from -0.10 to -0.40 (p<0.01), while correlation R between heat evaluation and acoustic comfort ranges from 0.20 to 0.50 (p<0.01) in all survey sites. This means that when heat evaluation is high, subjective loudness is low, whereas acoustic comfort is high.

Table 8. Chi-square test of correlation coefficients between heat evaluation and subjective loudness as well as acoustic comfort, where the significance levels (2-tailed) are also shown.

Survey sites	Subjective loudness (Correlation/significance)	Acoustic comfort (Correlation/significance)	Degree of freedom
Shi Tou Dao	-0.35/0.00 **	0.36/0.00 **	597
Railway Station	-0.34/0.00 **	0.22/0.00 **	445
Qiu Lin	-0.20/0.00 **	0.37/0.00 **	458
Hui Zhan	-0.19/0.00 **	0.32/0.00 **	689
Le Song	-0.30/0.00 **	0.42/0.00 **	628

**indicates $p<0.01$, and * indicates $p<0.05$

4.2 Humidity

The relationship between relative humidity and subjective loudness and the relationship between relative humidity and acoustic comfort are also analysed. In Table 9, the Pearson correlation between relative humidity and subjective loudness is shown to be significant (p<0.01) in four survey sites. Interestingly, the correlation coefficient R between relative humidity and subjective loudness is positive in Qiu Lin (0.30) and in Hui Zhan (0.26) where the mean of relative humidity is 59.15% and 61.42% (Table 6) , whereas, there is a negative correlation coefficient in Railway Station (-0.29) and Le Song (-0.33), where the mean of relative humidity is 68.72% and 68.54% (Table 6). From the analysis of the measured data, it seems that in the case study sites, subjective loudness is higher with a higher relative humidity when relative humidity is relatively lower. However, subjective loudness is lower with a higher relative humidity when relative humidity is relatively higher. The results also show that the correlation between relative humidity and acoustic comfort is significant (p<0.01) in all survey sites. The correlation is positive in Shi Tou Dao, Railway, and Le Song, with correlation coefficients ranging from 0.16 to 0.35, whereas the correlation is negative in Qiu Lin and Hui Zhan, with correlation coefficients at -0.32 and -0.33, respectively. It is noted, however, to draw more general conclusions in this respect, it would be useful to have more case studies.

Table 9. Pearson correlation coefficients between relative humidity and subjective loudness as well as acoustic comfort, where the significance levels (2-tailed) are also shown.

Survey sites	Subjective loudness (Correlation/significance)	Acoustic comfort (Correlation/significance)	Degree of freedom
Shi Tou Dao	-0.10/0.11	0.16/0.01 **	584
Railway Station	-0.29/0.00 **	0.35/0.00 **	435
Qiu Lin	0.30/0.00 **	-0.32/0.00 **	428
Hui Zhan	0.26/0.00 **	-0.33/0.00 **	651
Le Song	-0.33/0.00 **	0.23/0.00 **	599

** indicates p< 0.01, and * indicates p< 0.05

The relationship between perceived humidity and subjective loudness, as well as between perceived humidity and acoustic comfort, is shown in Table 10, where Chi-square test and correlation coefficient R are also provided. The correlation R between perceived humidity and subjective loudness ranges from -0.08 to -0.33 (p<0.01), and the correlation R between perceived humidity and acoustic comfort ranges from 0.21 to 0.31 (p<0.01) in all survey sites. These results indicate that when perceived humidity is high, subjective loudness is low, and acoustic comfort is high.

Table 10. Chi-square test correlation coefficients between perceived humidity and subjective loudness as well as acoustic comfort, where the significance levels (2-tailed) are also shown.

Survey sites	Subjective loudness (Correlation/significance)	Acoustic comfort (Correlation/significance)	Degree of freedom
Shi Tou Dao	-0.30/0.00 **	0.31/0.00 **	597
Railway Station	-0.33/0.00 **	0.23/0.00 **	445
Qiu Lin	-0.32/0.00 **	0.24/0.00 **	458
Hui Zhan	-0.08/0.09	0.21/0.00 **	689
Le Song	-0.24/0.00 **	0.23/0.00 **	628

** indicates p< 0.01, and * indicates p< 0.05

The effect of the interaction between air temperature and relative humidity on subjective loudness and acoustic comfort has been also considered, given that previous studies suggested that such interactions could affect users' environmental evaluation [43]. In Table 11, the results of multiple regressions between such interaction and subjective loudness as well as acoustic comfort are given, where the adjusted R square, and Significance are also provided. It can be seen that, in most of survey sites, the evaluation of subjective loudness and acoustic comfort have significant relationships with interaction of air temperature and relative humidity ($p<0.05$), where the adjusted R square is 0.04 to 0.14 for subjective loudness and 0.04 to 0.39 for acoustic comfort.

Table 11. Multiple regression between interaction of air temperature and relative humidity and subjective loudness as well as acoustic comfort, where the adjusted R square and significance levels (2-tailed) are also shown.

Survey sites	Subjective loudness (Adjusted R square /significance)	Acoustic comfort (Adjusted R square /significance)	Degree of freedom
Shi Tou Dao	0.02/0.25	0.04/0.00 **	597
Railway Station	0.14/0.00 **	0.37/0.00 **	445
Qiu Lin	0.04/0.00 **	0.06/0.00 **	458
Hui Zhan	0.11/0.00**	0.38/0.00 **	689
Le Song	0.06/0.00 **	0.39/0.00 **	628

** indicates $p<0.01$, and * indicates $p<0.05$

4.3 Luminance

The relationships between luminance and evaluation of acoustics are shown in Table 12. The correlation between luminance and subjective loudness is significant ($p<0.01$) in three survey sites, with R ranging from -0.10 to -0.23. The correlation between luminance and acoustic comfort is significant ($p<0.01$) in all survey sites, with R ranging from 0.18 to 0.32. These results suggest that when luminance is higher, subjective loudness is low, and acoustic comfort is high.

Table 12. Pearson correlation coefficients between luminance and subjective loudness as well as acoustic comfort, where the significance levels (2-tailed) are also shown.

Survey sites	Subjective loudness (Correlation/significance)	Acoustic comfort (Correlation/significance)	Degree of freedom
Shi Tou Dao	0.02/0.60	0.32/0.00 **	584
Railway Station	-0.07/0.07	0.18/0.00 **	435
Qiu Lin	-0.11/0.00 **	0.27/0.00 **	428
Hui Zhan	-0.10/0.03 *	0.23/0.00 **	651
Le Song	-0.23/0.00 **	0.29/0.00 **	599

** indicates $p<0.01$, and * indicates $p<0.05$

The relationships between brightness evaluation and evaluation of acoustics are shown in Table 13, where Chi-square test and correlation coefficient R are also provided. It can be seen that the correlation between brightness evaluation and subjective loudness is significant (p<0.01) in all survey sites, with R ranging from -0.16 to -0.33. There is also significant correlation (p<0.01) between brightness evaluation and acoustic comfort in all survey sites, with R ranging from 0.16 to 0.50. These results indicate that when brightness evaluation is high, subjective loudness is low, and acoustic comfort is high.

Table 13. Chi-square test of correlation coefficients between brightness evaluation and subjective loudness as well as acoustic comfort, where the significance levels (2-tailed) are also shown.

Survey sites	Subjective loudness (Correlation/significance)	Acoustic comfort (Correlation/significance)	Degree of freedom
Shi Tou Dao	-0.28/0.00 **	0.42/0.00 **	597
Railway Station	-0.29/0.00 **	0.50/0.00 **	445
Qiu Lin	-0.33/0.00 **	0.33/0.00 **	458
Hui Zhan	-0.22/0.00 **	0.28/0.00 **	689
Le Song	-0.16/0.00 **	0.16/0.00 **	628

** indicates p<0.01, and * indicates p<0.05

4.4 Visual

A number of previous studies [15] indicated that visual evaluation, which generally refers to the evaluation of interior decoration [34], has influence on the evaluation of acoustics in open space, but such research has been very limited in underground spaces. In Table 14 the relationship is presented between visual and acoustic evaluations. It can be seen that there is a significant correlation between visual evaluation and subjective loudness (p<0.01or p<0.05) in four survey sites, with R ranging from -0.12 to -0.37. The correlation between visual evaluation and acoustic comfort reaches a significant level (p<0.01) in all the survey sites, with R ranging from 0.21 to 0.36. These results indicate that when visual evaluation is high, subjective loudness is low, and acoustic comfort is high.

Table 14. Chi-square test correlation coefficients between brightness evaluation and subjective loudness as well as acoustic comfort, where the significance levels (2-tailed) are also shown.

Survey sites	Subjective loudness (Correlation/significance)	Acoustic comfort (Correlation/significance)	Degree of freedom
Shi Tou Dao	-0.36/0.00 **	0.32/0.00 **	597
Railway Station	-0.17/0.01 **	0.21/0.00 **	445
Qiu Lin	-0.37/0.00 **	0.36/0.00 **	458
Hui Zhan	-0.07/0.13	0.27/0.00 **	689
Le Song	-0.12/0.03 *	0.31/0.00 **	628

** indicates p<0.01, and * indicates p<0.05

5. Discussions

In the survey, the interviewees were asked to write down the most important environmental factor, i.e. sound, temperature, humidity, lighting, and visual. Statistical results in Figure 5 show that nearly 30% of respondents selected the sound environment as the most important factor. On the other hand, only about 5% of respondents said that none of the environmental factors was important. It would be interesting to examine whether the attitude of respondents towards the sound environment has an influence on subjective loudness and acoustic comfort.

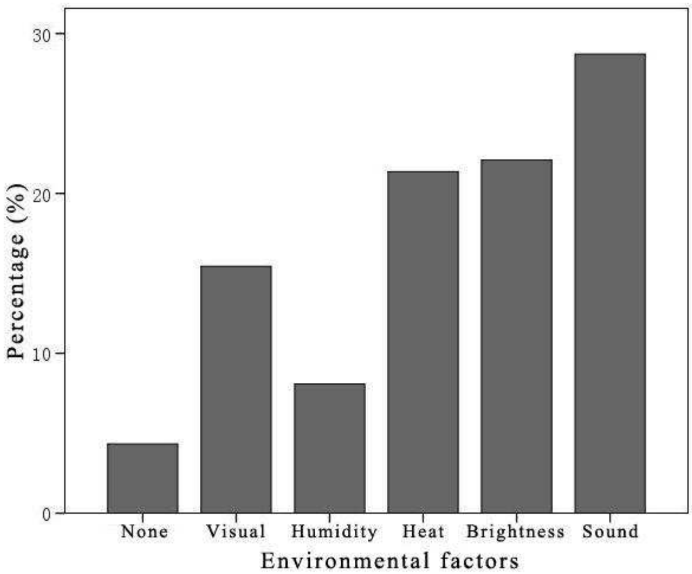


Figure 5. Evaluation of the most important factor among all environmental factors

The respondents were first grouped into two: a group who think environmental factors are important, and another group who think none of the environmental factors is important. The mean difference of subjective loudness and acoustic comfort between the two groups is shown in Table 15. Since it is useful to examine if the differences differ at different survey sites, comparisons are made for each survey site. It can be seen that the mean difference between the two groups is not significant in most survey sites.

Table 15. Mean difference in subjective loudness and acoustic comfort, between respondent group who think environmental factors are important, and who think none of the environmental factors is important, where the significance levels are also shown.

Survey sites	Subjective loudness (Mean difference /significance)	Acoustic comfort (Mean difference /significance)	Degree of freedom
Shi Tou Dao	0.34/0.02 *	-0.04/0.79	597
Railway Station	-0.22/0.15	0.48/0. 02 *	445
Qiu Lin	0.18/0.34	0.35/0.12	458
Hui Zhan	0.12/0.67	-0.27/0.31	689
Le Song	-0.30/0.12	0.29/0.23	628

** indicates $p<0.01$, and * indicates $p<0.05$

The respondents were then grouped differently with the first group who think that the sound environment is the most important factor and another group who selected other environmental factors. The mean difference shown in Table 16 is generally significant in terms of the evaluation of subjective loudness as well as acoustic comfort, with a significance level at $p \leq 0.01$ or $p \leq 0.05$ in four of the survey sites. The respondents who think that the sound environment is the most important factor gave higher subjective loudness, with a mean difference ranging from 0.16 to 0.39 in different survey sites. They also gave lower acoustic comfort evaluation, with a mean difference ranging from 0.07 to 0.32. In other words, the results suggest that the respondents' attitude to sound environment could influence their evaluation of subjective loudness and acoustic comfort.

Table 16. Mean difference in subjective loudness and acoustic comfort, between respondent group who think that the sound environment is the most important factor and who selected other environmental factors, where the significance levels are also shown.

Survey sites	Subjective loudness (Mean difference /significance)	Acoustic comfort (Mean difference /significance)	Degree of freedom
Shi Tou Dao	0.39/0.00 **	-0.32/0.00 **	502
Railway Station	0.17/0.02 *	-0.28/0.00 **	397
Qiu Lin	0.35/0.00 **	-0.20/0.05 *	381
Hui Zhan	0.16/0.19	-0.07/0.57	606
Le Song	0.24/0.00 **	-0.24/0.03 *	585

** indicates $p<0.01$, and * indicates $p<0.05$

6. Conclusions

Based on the questionnaire survey and the measurement conducted in five typical underground shopping streets, the evaluation of the sound environment with different space types and environmental characteristics in underground shopping streets was studied.

For spatial characteristics, the respondents' subjective loudness was higher in "street type" than in "square type" underground shopping streets when LAeq was high (75 dBA). The respondents' acoustic comfort was higher in "square type" than in "street type" underground shopping streets when LAeq was low (55 dBA). In the studied underground shopping streets, no significant difference in acoustic comfort was found between the first and second floors. In terms of spatial function, acoustic comfort was higher in dining spaces than in shopping spaces, with a given subjective loudness. Moreover, the type of selling spaces may have affected acoustic comfort too.

Regarding environmental characteristics, the subjective loudness is influenced by humidity and luminance, with correlation coefficients of about 0.10 to 0.30. The evaluation of acoustic comfort is influenced by air temperature, humidity, and luminance, with correlation coefficients of 0.1 to 0.4. The correlation between environmental evaluation and the subjective loudness, and acoustic comfort are all significant, with correlation coefficients of 0.1 to 0.5. Moreover, respondents' attitude to sound environment could influence their evaluation of subjective loudness and acoustic comfort.

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